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TEACHING UPPER-SECONDARY STUDENTS ABOUT CONSERVATION OF MECHANICAL ENERGY: TWO VARIANTS OF THE SYSTEM APPROACH TO ENERGY ANALYSIS

Asila Halilović,
Vanes Mešić, Elvedin Hasović,
Andrej Vidak

Abstract. *Conventional teaching about the law of conservation of mechanical energy (LCME) often results with students trying to solve problems by remembering similar problems they already covered in classes. Consequently, many students fail to transfer their knowledge to simplest real-life problems. Therefore, a pre-test – post-test quasi-experiment was conducted to evaluate the effects of an alternative, system-based approach to teaching about LCME. The study included 70 upper-secondary students from the First Bosniak Gymnasium Sarajevo, Bosnia and Herzegovina. Firstly, all students learned about energy in a conventional way. Then they wrote a test on LCME and had three additional hours of teaching about this topic, where one group of students learned in line with the forces-variant of the system approach (e.g., discussing conservative and non-conservative forces) and the other group with the process-variant of the same approach (e.g., discussing system's states and processes like in thermodynamics). For both variants, only three hours of system-based teaching proved to substantially improve the students' level of LCME understanding compared to the level of understanding they had after conventional teaching. It follows that the system approach may work well at the upper-secondary level, if it is introduced through the scaffolding-and-fading technique.*

Keywords: *quasi-experiment, mechanical energy, teaching materials, teaching strategies*

Asila Halilović
First Bosniak Gymnasium Sarajevo, Bosnia and Herzegovina
Vanes Mešić, Elvedin Hasović
University of Sarajevo, Bosnia and Herzegovina
Andrej Vidak
University of Zagreb, Croatia

Introduction

Physics curricula around the world recognise energy as one of the core concepts in science (Duit, 2014), as it is fundamental in development of integrated scientific understanding of phenomena (Linn et al., 2006; National Research Council, 2012; Nordine et al., 2011). Importance of the energy concept is also recognised by PISA and TIMSS studies and is reflected in many science standards (National Research Council, 2012; Next Generation Science Standards, 2013).

However, research about students' energy conceptions keeps showing that students at all educational levels have significant difficulties with the concept of energy (Goldring & Osborne, 1994; Lawson & McDermott, 1987; Neumann et al., 2013; Pride et al., 1998). Concretely, students exhibit difficulties with understanding work-energy processes (Van Huis & Van den Berg, 1993), energy degradation and energy conservation (Goldring & Osborne, 1994; Liu & McKeough, 2005; Neumann et al., 2013). Thereby, a large number of studies detected conservation of energy as the most difficult aspect of the energy concept (Lindsey et al., 2012; Neumann et al., 2013; Van Heuvelen & Zou, 2001; Van Huis & Van den Berg, 1993). In fact, only a very few students develop deeper understanding of energy conservation until the time they finish secondary school (Herrmann-Abell & DeBoer, 2018).

For purposes of improving the quality of teaching about energy, it is useful to identify possible sources of above-mentioned students' difficulties. Firstly, it is important to note that many students' difficulties with the energy concept may be related to students' (mis)understanding of systems (Seeley et al., 2019; Van Heuvelen & Zou, 2001; Van Huis & Van den Berg, 1993). Consequently, students should be helped to recognize the importance of carefully choosing the physical system, if one wants them to gain a functional understanding of energy conservation (Lindsey et al., 2012; Seeley et al., 2019). Such system-based

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approach to energy analysis is also promoted within the framework of Next Generation Science Standards (NGSS, 2013) in United States of America. In the system approach to energy analysis, one starts with defining the system of interest which automatically also defines the environment. Then typically one analyses the work of internal (acting within the system) and external forces (acting at the environment-system boundary) which could be conservative or non-conservative, for purposes of evaluating whether the system loses or gains energy. In other words, typically energy analysis heavily relies on discussion of forces. Alternatively, one may avoid introducing too many types of forces, and instead more heavily rely on language of thermodynamics, which includes thinking about different states of a system, processes by which a system evolves through different states and conversion of mechanical energy to other types of energy and vice versa.

Although there are strong theoretical arguments that speak for its usefulness, it seems that the system approach to energy analysis is only rarely introduced in upper-secondary physics textbooks and even more rarely is it consistently applied in practice (e.g., Abasbegovic & Musemic, 1998; Colic, 2001; Crundell et al., 2014; Sang et al., 2012). A possible reason for not including the system approach to energy analysis into upper-secondary curricula could be related to the fact that at the university level it is typically applied in a way which includes an intensive discussion about forces (e.g., internal, external, conservative, non-conservative). Taking into account that students at all educational levels already have many misconceptions about the basic concept of force (Aviani et al., 2015), it is somewhat reasonable why in the past many textbooks avoided to introduce the system approach to energy analysis. As a result, a conventional approach that is focused on idealised, quantitative problems still prevails in practice. Thereby, explicit strategies for reasoning about LCME are only rarely introduced and even more rarely are they consistently applied in problem solving. Consequently, many students try to solve LCME problems by using the strategy of remembering superficially similar problems they had already covered in classes (Chi et al., 1981). Such an approach certainly does not promote development of the sub-competences needed to identify whether or not conservation of mechanical energy holds in real-life situations (Bryce & MacMillan, 2009).

However, it seems that there are also some difficulties related to implementation of the system approach in practice. Concretely, a recent study by Seeley et al. (2019) showed that even upper-secondary physics teachers struggle with a consistent system approach to energy analysis and another study showed that many primary teachers assume that conservation of energy applies to individual objects, rather than to a closed system (Kruger, 1990; Tobin et al., 2012). This could be partly explained by the fact that these teachers did not have an opportunity to learn about the system approach to energy analysis, because it was not sufficiently represented in their initial teacher education. In addition, it is important to note that even university students often struggle to recognize how choice of a system influences the applicability of conservation of mechanical energy (Lindsey et al., 2012). This could be related to the fact that many students are not aware that choosing a physical system has a role in defining an isolated system and in reasoning about interaction between a system and its environment, in general (Grimellini-Tomasini et al., 1993). For example, depending on the choice of the system, there can be gravitational work done on the system if the system does not include Earth, or system could be isolated and possess gravitational potential energy when system includes Earth (Lindsey et al., 2009).

Next, it is useful to describe activities that earlier research has shown to be effective for learning about LCME. For example, one practice that proved to help college students to reason about conservation of mechanical energy was explicit teaching on how to define systems (Ding et al., 2013). In addition, at the level of lower-secondary school an approach has been described which avoids discussion about forms of energy and focuses on connections between energy, systems, and fields that mediate interaction-at-a-distance (Fortus et al., 2019). However, a weakness of that approach could be related to the fact that it does not sufficiently pay attention to tracking the evolution of system states over the time. In fact, besides defining systems, another important aspect of energy analysis is tracking changes of system states over the time. Actually, depending on the choice of a time interval in which one observes the system, mechanical energy could be conserved or not. Consequently, Solbes et al. (2009) created a teaching sequence with activities that encouraged post-compulsory secondary students to describe a given system at "initial" and "final" instant of time, and research results suggested its positive effect on students' understanding of energy conservation. A similar research has been conducted by Papadouris and Constantinou (2016) with lower-secondary students, as well as by Van Heuvelen and Zou (2001) with university students. However, it seems that in none of these studies sufficient attention has been paid to providing the students with explicit problem-solving strategies and to discussing real-life problems for which mechanical energy is *not* conserved. On the other hand, providing the students with explicit cognitive strategies is considered to facilitate construction of understanding (Anderson & Bloom, 2001).

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Research Aim

According to Nordine et al. (2011) there are already many research papers on effective teaching about energy, but there is still need for more studies that would explore the effectiveness of these teaching approaches in different contexts. In fact, although at the university level the system approach to energy analysis proved to be effective, at the upper-secondary school level the system approach to energy analysis has not been sufficiently studied in general and particularly it has not been explored how different variants of the system approach (e.g., including or excluding conservative and non-conservative forces from energy analysis) compare when it comes to developing students' understanding of conservation of mechanical energy. Consequently, the system approach to energy analysis is avoided in most upper-secondary school physics textbooks and conventional approach is still prevalent in physics classrooms.

However, the conventional approach proves to be largely ineffective when it comes to developing functional LCME knowledge in upper-secondary students (Bryce & MacMillan, 2009; Halilovic et al., 2020). Therefore, the aim of this study was to explore whether an alternative, system-based approach to energy analysis may help upper-secondary school students to significantly improve their understanding about the conservation of mechanical energy. Concretely, the following research questions were raised:

1. May three hours of additional, system-based teaching about LCME significantly improve upper-secondary students' understanding of LCME compared to the level of understanding they had after conventional teaching?
2. Is the processes-variant of the system approach (i.e., relying more on speaking about systems' states and processes, like in thermodynamics) more effective than the forces-variant of the system approach (i.e., including discussion about conservative and non-conservative forces) when it comes do developing upper-secondary students' understanding about LCME?

It is important to note that here the construct of understanding is used in line with the theoretical framework by Wiggins and McTighe (1998, pp.44-62). They argue that one who truly understands can interpret, can explain, can apply and is able to take perspective.

This research is significant because it illustrates how the system approach to energy analysis may be adapted to work well for developing upper secondary school students' understanding about energy. Thereby, two variants of the system approach are described which could meet the needs and interests of a wide range of physics teachers. It is expected that the implementation of these teaching approaches in upper-secondary school physics classrooms could result in development of deeper understanding about the energy concept compared to understanding developed as a result of conventional teaching. This particularly holds for Canton Sarajevo, for which it has been found that upper-secondary school students fail to develop even the most basic understanding of energy conservation (Halilovic et al., 2020). Finally, the test developed for purposes of measuring students' understanding of conservation of mechanical energy, may be very useful for physics teachers, when it comes to identifying misconceptions and sparking productive classroom discussions about energy.

Research Methodology

Research Design

An overview of the research design is presented in Table 1.

Table 1
Overview of Research Design

Group	Intervention 1	Test 1	Intervention 2	Test 2
Bosniak Gymnasium Sarajevo (FV)	Conventional teaching at upper-secondary school level	Understanding of conservation of mechanical energy	Forces variant of the system approach to energy analysis	Understanding of conservation of mechanical energy
Bosniak Gymnasium Sarajevo (PV)	Conventional teaching at upper-secondary school level	Understanding of conservation of mechanical energy	Processes variant of the system approach to energy analysis	Understanding of conservation of mechanical energy

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Group	Intervention 1	Test 1	Intervention 2	Test 2
Third Gymnasium Sarajevo (C1)	Conventional teaching at upper-secondary school level	Understanding of conservation of mechanical energy	-	-
University of Zagreb (C2)	Conventional teaching at upper-secondary and at university level	Understanding of conservation of mechanical energy	-	-

The within-subject part of the research design allowed us to explore whether additional three teaching hours based on a system approach to energy analysis (*intervention 2*) can result in a significant learning gain. The between-subject part of the research design allowed us to compare the relative effectiveness of the forces variant (FV) of the system-based approach to the processes variant (PV) of the system-based approach. It also allowed us to compare the achievement of the two experimental groups FV and PV with a group C1 that only received a conventional teaching at the upper-secondary school level, as well as with a group C2 that received conventional teaching on conservation of mechanical energy at the upper-secondary school and university level.

The alternative teaching interventions (*intervention 2*) were carried out in October and November 2020 in First Bosniak Gymnasium Sarajevo, Bosnia and Herzegovina. For purposes of minimizing the disruption of everyday school processes random assignment of students to comparison groups could not be used. However, teaching interventions were randomly assigned to one of the two existing groups, in order to minimize the threats to internal validity. Students in both comparison groups (FV and PV) were taught by the same teacher. At the time of the study, the teacher had 12 years of experience in teaching upper-secondary school physics.

The pre-test (test 1) was conducted one week before the implementation of the alternative teaching interventions, and the post-test was carried out one week after the interventions were completed. The research took place during COVID pandemics in Sarajevo. At that time, the Ministry of Education, Science and Youth of Canton Sarajevo had ordered that all teaching has to be moved to an online environment. Therefore, the teaching – learning sequences were adapted for implementation in an online environment. Concretely, in this study, all online classes during the intervention took place over Google Meet calls, with teaching materials adapted to be used and shared with students on-screen during the classes. Furthermore, in order to ensure test objectivity, all testing took place with switched-on cameras. The teacher gave students an explanation about testing purposes and ensured that it would have no effect on their final grades. The same approach to testing has been also used with groups C1 (Third Gymnasium Sarajevo students) and C2 (University of Zagreb students).

Participants

In this research the target population consisted of final-year upper-secondary school students and the sample of participants was obtained by means of the convenience sampling technique (Ary et al., 2009). All participants were informed about the nature of the study and they gave their informed consent to participate in the study. The participants were assured that the principles of confidentiality and anonymity would be adhered to in the study.

The study participants in groups FV and PV were mostly 18-year-old upper-secondary school students who were enrolled either in the National Program or Cambridge International Program at the First Bosniak Gymnasium Sarajevo, Bosnia and Herzegovina. Concretely, all 70 fourth year students who wrote the pre-test (test 1) as well as the post-test (test 2) were included in the sample. Furthermore, group C1 consisted of 45 fourth year upper-secondary school students from the Third Gymnasium Sarajevo, and group C2 consisted of 138 first-year students from the Faculty of Chemical Engineering and Technology (University of Zagreb, Croatia).

Gender distribution of the student sample was as follows: in FV out of 38 students, 39.5% were male and 60.5% female; in PV out of 32 students 46.9% were male and 53.1% female; in C1 out of 45 students, 37.8% were male and 62.2% female; and finally, in C2 out of 138 students, 28.3 % were male and 71.7% female.

About 66% of students in FV, and about 38% of students in PV were enrolled in the National Program, and the rest were enrolled in the Cambridge International Program. As it was not allowed to mix students from different classes, a more even gender/curriculum distribution for groups FV and PV could not be obtained. However, it could be shown that the groups FV and PV entered the teaching intervention with a similar level of foreknowledge; the between-group difference on test 1 (pre-test) was not statistically significant (t=-0.89, p=.38).

Finally, it is important to note that students from groups FV, PV and C1 had already learned about all different

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aspects of the energy concept in line with the conventional teaching in lower-secondary school, and also during previous 3 years of upper-secondary school. In addition, students from C2 had also learned about the energy concept at the university level. In fact, they took the test immediately after covering the concept of energy in their introductory physics course.

Relevant Characteristics of the Curriculum

The existing physics curriculum for the lower-secondary schools and upper-secondary schools in Canton Sarajevo largely boils down to listing topics content. Therefore, the deeper insight into curricular practice can be only gained through analysis of textbooks that are approved for use in Canton Sarajevo (e.g., Abasbegovic & Musemic, 1998; Colic, 2001; Muratovic & Gabela, 2011). In Canton Sarajevo, students start their formal physics education in Year 7 of lower-secondary school. However, they learn about the mechanical energy concept for the first time in Year 8 of lower-secondary school when they are on average 13- year-old, and the focus of teaching is on forms and transformations of energy. After nine years of lower-secondary school education, students from the sample were expected to learn more in depth about the mechanical energy concept in Year 1 of upper-secondary school (15- year-old students), and Year 3 if they take Physics as elective subject. In Year 1 students learn to apply the law of conservation of mechanical energy in cases when transformations of various forms of mechanical energy take place, mostly doing calculations (Colic, 2001). In Year 3 students learn about the concepts that are important for applying the law of conservation of mechanical energy (LCME), e.g., isolated system, internal and external forces, conservative and non-conservative forces (Abasbegovic & Musemic, 1998). Students are expected to use these concepts for solving work-energy and LCME problems. However, a strategy on how to use LCME in problem solving is typically not thoroughly discussed. Consequently, the most common approach to teaching laws of conservation in Canton Sarajevo is the inductive approach, as it is implicitly assumed that by solving a series of numerical tasks students will eventually develop "a feeling" about how LCME is applied. In other words, students most often do not develop relevant strategic knowledge related to the use of LCME.

Difficulties in developing upper-secondary school students' understanding about conservation of mechanical energy are probably not limited to the National curriculum in Canton Sarajevo, and Bosnia and Herzegovina. Useful insights about educational practices at the international level can be gained by inspecting some popular international study programs, such as the Cambridge program. Cambridge International Advanced Subsidiary and Advanced (AS & A) Level Physics syllabus introduces the concept of energy and its conservation as useful accounting tools that help students to understand the behaviour of physical systems. Students are expected to give examples, and explain transformation and conservation of energy, and apply the principle of conservation of energy to simple examples. LCME and its application is not named explicitly in the AS level syllabus. An inspection of two textbooks that are designed to facilitate implementation of the Cambridge program showed that intervention of work and energy concepts does not follow a systems-based approach, although students are expected to know how to solve simple numerical tasks that involve LCME (Crundell et al., 2014; Sang et al., 2012). It was also important to inspect the Physics curriculum for upper-secondary schools in Croatia, to see how it introduces the concept of energy and its conservation. The curriculum lists learning outcomes but it does not mention the system concept at all. The approach to concept of energy is very similar to everything already stated above for the curriculum in Canton Sarajevo and the Cambridge International Program. Even at university level the system approach to energy analysis is not included, as could be found through an inspection of one of the textbooks the students use at the Faculty of Chemical Engineering and Technology, University of Zagreb (Kulisic, 2005). It can be concluded that not only curricular materials for upper-secondary schools in Canton Sarajevo, but also curricular materials at the regional and international level, still fail to promote development of explicit strategic knowledge related to reasoning about conservation of mechanical energy.

Teaching Interventions

The alternative teaching interventions were conducted within the context of the regular teaching timetable, over the course of three weeks and three teaching hours in total. Students from FV learned about conservation of mechanical energy by using the forces variant of the system approach to energy analysis, while in PV the processes variant of the system approach has been used. Overview of research and teaching activities is given in Table 2.

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Table 2
Overview of Teaching Activities

Teaching time	Group 1 (FV)	Group 2 (PV)
60 min	**Week 1** Introduction of the forces-based strategy (FBS) to reasoning about LCME and its application in energy analysis of a chosen system Teaching objectives: 1) present different forms of mechanical energy 2) explain the term isolated system 3) distinguish internal, external, conservative, and non-conservative forces, and explain how they can affect a system's mechanical energy 4) demonstrate how the introduced FBS strategy may be used for reasoning about energy conservation for different system choices and time intervals (teacher modelling)	**Week 1** Introduction of the processes-based strategy (PBS) to reasoning about LCME and its application in energy analysis of a chosen system Teaching objectives: 1) present different forms of mechanical energy 2) explain the term isolated system 3) explain how system's state (mechanical energy) changes as a result of different processes 4) demonstrate how the introduced PBS strategy may be used for reasoning about energy conservation for different system choices and time intervals (teacher modelling)
60 min	**Week 2** Analysis of conservation of mechanical energy of a system example based on FBS (example: video of two objects connected with a string over a massless pulley) Teaching objectives: 1) work with students through another example of applying the FBS strategy (teacher-student interaction)	**Week 2** Analysis of conservation of mechanical energy of a system example based on PBS (example: video of two objects connected with a string over a massless pulley) Teaching objectives: 1) work with students through another example of applying the FBS strategy (teacher-student interaction)
60 min	**Week 3** Analysis of conservation of mechanical energy of a system example based on FBS (students in groups analyse video of an object on a compressed massless spring) Teaching objectives: 1) engage the students in applying the FBS strategy on their own and provide them with constructive feedback (student activity)	**Week 3** Analysis of conservation of mechanical energy of a system example based on PBS (students in groups analyse video of an object on a compressed massless spring) Teaching objectives: 1) engage the students in applying the PBS strategy on their own and provide them with constructive feedback (student activity)

During the first week of the intervention the teacher verbally introduced students to the new approach to energy conservation concept for the specific group. This introduction was immediately followed by visualization of the strategy for reasoning about LCME and application activities. During the week 2 and 3, teaching provided a context intended to help students appreciate significant sub-competencies needed to strengthen their understanding of conservation of mechanical energy, and also to acquire contextualized insights into application of the law of conservation of mechanical energy.

The two teaching interventions only differed with respect to the strategy that has been used for facilitating reasoning about conservation of mechanical energy. In FV students learned with a strategy that heavily relies on a deep analysis of forces (forces-based strategy – FBS), which is similar to approaches that are described in some introductory physics textbooks for the university level of education (e.g., *Physics for Scientists and Engineers* by Tipler and Mosca, 2008). In PV a simpler language has been used. For example, mentioning of conservative and non-conservative forces has been avoided, and there was a higher emphasis on terms such as "state of the system", "processes that lead to changes of the state" and other terms that are often used in the language of thermodynamics. Because this approach was mainly based on thinking about processes (in general) that could result in an increase/decrease of the system's energy, the corresponding strategy was named as "processes-based strategy" (PBS). As it relies on fewer technical terms, the processes-based strategy potentially reduces the intrinsic cognitive load (Sweller, 1994) and makes easier the transition from mechanics to thermodynamics. In order to facilitate the use of FBS and PBS, they have been introduced to students through external visualizations (Figure 1).

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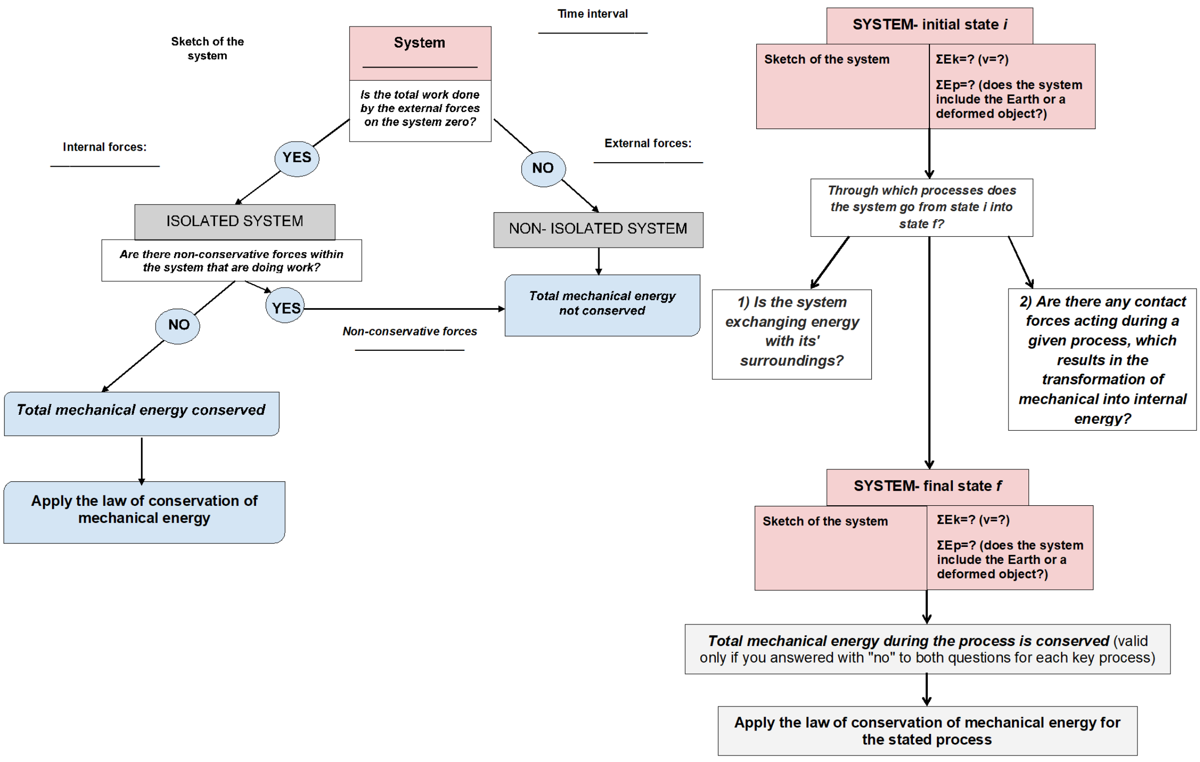
Figure 1
External Visualizations for Forces-based Strategy (left) and Processes-based Strategy (right)



Aside from the described differences related to the use of different strategies to reasoning about LCME, all other aspects of the learning and teaching were approximately the same for FV and PV. Concretely, both alternative teaching interventions addressed the complex concept of energy conservation through reasoning about system choice and time evolution of the physical system over time. Both interventions used the same scaffolding-and-fading technique (Davis & Miyake, 2004), as well as the same examples and same expected learning outcomes. In both groups students were encouraged to draw a sketch of a system they analyse, which should help them become more aware of the fact that the choice of a system they observe will affect conservation of mechanical energy. Originally the plan was to facilitate students' learning through in-classroom demonstrations of specific problem situations. However, as teaching had to be done online, the students were shown videos of those demonstrations so they could watch them and do all the rest of the planned activities. The predict-observe-explain technique was used whenever it was possible. Teacher would start the class by presenting the video of a problem situation. Afterwards, she moderated the classroom discussion about the phenomena displayed in the video. Worksheets for each of the visualization and application activities were sent to students prior to the online classes.

The problem situations were selected to be context-rich and to provide the students with the opportunity to appreciate system, and time interval choices. Concretely, the students were encouraged to analyse real-life problem situations that included friction and air resistance, and not only idealised situations that limit students' understanding of the energy concept. The amount of teacher support in applying the PBS and FBS strategies has been reduced gradually.

For purposes of further illustration of the two teaching interventions, it is useful to analyse some of the activities that have been conducted in both groups during the application lessons. Concretely, these lessons covered a situation which included two objects connected with a string over a massless pulley. For the purpose of visualization teacher played the video at the beginning of the lesson, and then started discussion with students. Firstly, students were expected to verbalise what they observed in the video from the moment the larger object starts to fall down until both objects completely stop. They were guided to identify relevant forces/processes, as well as to discuss about possible choices of the physical system. Next, students had the task to determine whether mechanical energy was conserved, and to connect the initial and final state through LCME if applicable, for the given examples. First example the students

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analysed was when the system consists of the Earth and two connected objects during the time interval from the moment the larger mass is released to fall until the moment just before it hits the ground. Next, students analysed the situation in which the system consists of the Earth and two connected objects during the time interval from the moment the larger mass just touches the ground, until the smaller mass reaches the maximum height above the ground. At the end, students submitted photos of their completed worksheets over the Google Classroom, and teacher shared some of those completed work on-screen with everyone and discussed with the class about their answers.

At the end of each lesson the students were presented with one problem situation for the homework. The examples were carefully planned so that they were continuation of examples discussed during the class, but introduced some conflicting aspects to it, like choice of different time interval or system, or same system, but with air added. Each time, at the beginning of the next lesson, teacher started with short discussion about students' homework solution.

In line with the scaffolding-and-fading technique (Davis & Miyake, 2004), during the third week of intervention, students were expected to use the algorithm with minimal help from the teacher. So, they were presented with the new problem situation at the beginning of the class, and then they had to work in groups (3-4 students) while analysing the given example to determine whether mechanical energy was conserved, and to connect the initial and final state through LCME if applicable. After groups submitted their answers and worksheets, teacher shared those on screen with everyone, and discussed about their answers.

Assessment Instrument

For purposes of answering the research questions, it was necessary to design a test that measures students' conceptual understanding of the energy concept with special focus on conservation of mechanical energy. Thereby an indicator of conceptual understanding was the students' ability to reason about changes of mechanical energy in the context of real-life situations, for various system and time interval choices. In order to validly measure conceptual understanding, it was important that test items do not describe the same problems that had been explicitly discussed within classes (Mayer, 2002; Vidak et al., 2018). Eventually, a 14-item multiple-choice test has been developed. For each of the test items, there were four answering options, with one correct answer and three distracters. The distracters were chosen to reflect typical students' difficulties, as reported in earlier research, including our own exploratory study which contained open-ended tasks and has been also conducted with upper-secondary school students from Canton Sarajevo (Halilovic et al., 2020).

Five of the items were adapted from widely known and extensively validated surveys such as Energy and Motion Conceptual Survey (EMCS) by Singh and Rosengrant (2003), and Energy Concept Assessment (ECA) by Ding et al. (2013). Concretely, items 8, 13 and 14 were adapted from EMCS, and items 1 and 6 from ECA. The remaining 9 items were an original contribution. These items were developed with an aim to secure content validity, i.e., to include most important LCME applications typically covered in physics courses, at the upper-secondary school level. For purposes of collecting additional validity evidence, an online teacher survey has been conducted. For each of the items the upper-secondary physics teachers were asked the following questions:

1. Is the knowledge measured by this item relevant for understanding conservation of mechanical energy? (Yes, No)
2. Is this item physically correct? (Yes, No)
3. How much do you like this item on a scale from 1 (not at all) to 5 (very much)?

Eventually the survey has been filled out by 23 teachers. Only one teacher meant that one of the test items (item 1) does *not* measure knowledge that is relevant for understanding conservation of mechanical energy, although reasoning about conservation of mechanical energy may also include thinking about kinetic energy of a system. Similarly, for only one item (item 13) one of the teachers meant that one should point out that friction is neglected although the item described a rough incline for which friction *cannot* be neglected. The average "like measure" amounted to 4.52 out of 5 points, which indicates that the LCME instrument has been well received by the teachers.

The structure of the instrument was as follows:

- Group A (GA) of items for which students were expected to: *use basic knowledge* about the energy concept (concretely: compare final kinetic energies given the information about initial heights; identify a

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system which includes the given forms of mechanical energy; compare work in two different contexts; relate performed work with change of energy; determine kinetic energy for a two-body system);

- GA included the items: 6 (*object on a spring*), 8 (*satellite motion*), 13 (*rough incline*), 14 (*smooth slides*), 1 (*two runners*)
- Group B (GB) of items for which students were expected to: *identify a system for which mechanical energy is conserved* in the given time interval;
- GB included the items: 2 (*falling ball - no air resistance*), 5 (*falling ball – collision*), 3 (*falling ball – with air resistance*), 12 (*smooth and rough incline*)
- Group C (GC) of items for which students were expected to: *identify a time interval for which mechanical energy is conserved* for the given system;
- GC included the items: 4 (*falling ball*), 11 (*two blocks connected over a massless pulley*)
- Group D (GD) of items for which students were expected to: *identify a system as well as time interval* for which mechanical energy is conserved;
- GD included the items: 7 (*falling stone*), 9 (*object ejected by vertical spring – mechanical energy conserved*), 10 (*object ejected by vertical spring – mechanical energy not conserved*)

Some of the misconceptions that may be identified with this instrument are as follows: kinetic energies of objects moving in opposite directions cancel out (*item 1*); a system consisting of a single body possesses gravitational potential energy (*item 2*); an incline can help you to invest less work (*item 13*); whether mechanical energy is conserved does not depend on system or time interval choice, but only on surface features of the physical situation (e.g., it is conserved for all "pulley problems") (*item 11*); if there is an external force acting on the system the mechanical energy cannot be conserved (even if the force vector is all the time perpendicular on the displacement vector) (*item 8*); LCME may be used to relate initial and final state of the system even if the observed time interval includes an inelastic collision or friction force (*item 5*), etc.

The same instrument has been used as pre-test (test 1) and post-test (test 2). Students were given 45 minutes to solve the test. Based on students' post-test scores it was possible to calculate the Cronbach's alpha which amounted to .6 which is relatively low, but acceptable (Bowling, 2005, p. 397). The instrument as a whole is available on the following web address: http://pierre.fkit.hr/~avidak/LCME.pdf.

Data Analysis

Students' answers to each of the test items at pre- and post-test were entered into a database. Then the database has been recoded. Each correct answer has been coded by one and all other answers with a zero. Then this recoded database has been used for running statistical analyses that were relevant for fulfilling the research aims. First, pre-test and post-test scores along with their standard deviations were calculated. Also paired *t*-tests were conducted for purposes of exploring whether the gains in FV and PV were statistically significant, and an analysis of covariance has been used for purposes of identifying the relative effectiveness of interventions in FV and PV. Taking into account that students from C1 and C2 wrote the test in only one occasion, achievement differences between FV, PV, C1 and C2 were analysed by means of analysis of variance.

Research Results

Table 3 provides information about pre-test and post-test scores of students from groups FV and PV who additionally learned about LCME by using a system approach to energy analysis.

Table 3
Mean Values and Standard Deviations (in parentheses) of Pre-test and Post-test Scores across the Individual Experimental Groups (FV) and (PV)

	FV	PV
Pre-test	4.84 (1.94)	4.41 (2.15)
Post-test	8.24 (2.39)	8.38 (2.79)

Note: The theoretical maximum of the test scale was 14 points

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From comparing pre-test with post-test scores, it is evident that for both groups there was a substantial learning gain. Next, it has been checked whether this learning gain was statistically significant. For each of the two intervention groups a separate paired *t*-test has been conducted. For the group which used the process approach (PV) the difference between post-test and pre-test scores was statistically significant, $t(31) = -7.02$, Cohen's $d = 2.01$. In fact, the average percentage of correct answers increased from 28.9% to 59.8% which is a large effect. Similarly, in the group which used the forces analysis approach (FV) the additional 3 hours of teaching intervention also resulted in significant differences between pre-test and post-test scores, $t(37)=-8.30$, Cohen's $d=1.71$. The average percentage of correct answers increased from 34.6% to 58.8% which is also a large effect.

Next, between-groups comparisons have been performed. Table 4 shows test scores for all groups, so pre-intervention results of group FV and PV can be compared with a similar group of students from another Canton Sarajevo gymnasium, as well as with a group of university students.

Table 4
Mean Values and Standard Deviations (in parentheses) of Pre-test and Post-test Scores across all Groups

Group	Intervention 1	Test 1	Intervention 2	Test 2
FV	Conventional teaching at upper-secondary level	4.84 (1.94)	Forces variant of the system approach to energy analysis – 3 hours	8.24 (2.39)
PV	Conventional teaching at upper-secondary level	4.41 (2.15)	Processes variant of the system approach to energy analysis – 3 hours	8.38 (2.79)
C1	Conventional teaching at upper-secondary level	4.42 (2.71)	-	-
C2	Conventional teaching at upper-secondary school and at university level	5.59 (2.32)	-	-

First, the effects of the two alternative interventions (FV and PV) have been compared. For purposes of controlling for pre-test differences, an analysis of covariance (ANCOVA) has been conducted. The data met the assumptions of ANCOVA, such as: independence of covariate and intervention, homogeneity of variances, normality and homogeneity of regression slopes. The results of ANCOVA showed that the between-group differences for FV and PV were not statistically significant, after controlling for pre-test differences, $F(1,67)= 0.21$, $p=.65$. It is also useful to note that the post-hoc statistical power of the ANCOVA analysis could be considered good ($1-\beta=.91$) only if the true effect size in the population were large ($f=.40$). If the true effect sizes were of medium ($f=.25$) or small magnitude ($f=.10$), the statistical power of the ANCOVA analysis would amount to .54 and .24, respectively.

Next, the test results from First Bosniak Gymnasium were compared with results from Third Gymnasium and University of Zagreb. First, all the groups' test scores were compared after they learned about LCME using a conventional approach. The difference between Bosniak Gymnasium and Third gymnasium students proved to be not statistically significant ($t(113)= 0.50$, $p=.62$), whereas the difference between Bosniak Gymnasium students and University of Zagreb students was statistically significant ($t(206)=-2.89$, $p< .001$), but relatively small (6.8 % better results in the University group). However, a comparison between Bosniak Gymnasium post-test scores with the scores from Third Gymnasium and University of Zagreb shows that now Bosniak Gymnasium students significantly outperform the students from the other two groups, $F(2, 250)=41.43$, $p< .001$. Concretely, Bonferroni post hoc analyses show a significant difference and large effect for the comparison of First Bosniak Gymnasium and Third Gymnasium (mean difference=3.88 points or 27.7%, $p= .001$). For the comparison of Bosniak Gymnasium post-test scores and scores obtained by University of Zagreb students a statistically significant, large effect was observed, too (mean difference=2.71 points or 19.3%, $p< .001$).

Discussion

After conventional LCME teaching the test scores across all groups were relatively low. Such low scores were not surprising; in another study which included 441 students from six upper-secondary schools in Canton Sarajevo (Halilovic, et al., 2020) it has been shown that conventional teaching results in extremely low students' understand-

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ing about LCME. It is important to note that such poor effects of conventional LCME teaching are not limited to Canton Sarajevo (Bosnia and Herzegovina) only. In fact, students from the University of Zagreb who came from all parts of Croatia were tested immediately after they received conventional teaching about energy, and their test scores proved to be very low. This additionally shows that conventional teaching is very limited when it comes to developing understanding about LCME. Furthermore, the fact that many upper-secondary school students enter university education without having learned about system approach to energy concept could partly explain why even university students struggle with use of LCME or work-energy theorem (Lindsey et al., 2009).

These results also show that students cannot be expected to develop deep understanding about LCME by merely solving a large number of idealized textbook problems. In fact, in conventional classes students are introduced to LCME within the context of simple, idealised situations (Bryce & MacMillan, 2009). Typically, they are not shown how conservation of mechanical energy may depend on system or time interval choice, and situations in which energy is *not* conserved are almost never discussed. Instead, students are shown how LCME may be applied for solving quantitative problems that are situated within various contexts (e.g., pulley, incline, and free fall). Then they are expected to solve a large number of quantitative problems that are pre-designed to allow for application of LCME. Due to the fact that upper-secondary students are often not introduced to relevant problem-solving strategies, they try to solve the problems by applying the strategy of remembering superficially similar problems that had been covered in classes (Chi et al., 1981). However, it is well known that solving a large number of standard textbook problems does not guarantee development of deep conceptual understanding (Kim & Pak, 2002), and that proved to be also true in the context of this research. By avoiding "complex strategies" for reasoning about LCME at the upper-secondary level, the chances of developing deep LCME understanding are eventually decreased. In fact, Arons (1997) already warned that oversimplifying physical concepts at lower educational levels may be counterproductive, in the long term.

Some "complex strategies" may also work well in the upper-secondary context. Actually, in this study it could be shown that taking only 3 hours of system-based teaching about LCME may result in large learning gains in upper-secondary school students. In fact, after having learned based on the system approach to energy analysis, students from First Bosniak Gymnasium even outperformed students from Zagreb who learned about LCME at upper-secondary school as well as at the university level. This is in line with previous research that has shown that system-based approaches are effective at the university level (Ding et al., 2013; Van Heuvelen & Zou, 2001). The findings from this study show that system-based approaches may also be effectively implemented at the upper-secondary school level. To that end it is important for a teaching-learning sequence to carefully introduce the concept of the physical system and its evolution over time. Also, an explicit strategy that facilitates reasoning about LCME should be provided and the teacher should thoroughly model its application to real-life problems, before requiring students to solve LCME problems on their own, which is consistent with the scaffolding-and-fading technique (Davis & Miyake, 2004).

For purposes of facilitating discussion, problem situations may be introduced through videos that show real-life situations. Inclusion of real-life situations in teaching about energy has been already advocated by Kubsch et al. (2019). This suggestion is reasonable because for developing deep understanding about mechanical energy conservation it is not sufficient to discuss idealised situations in which it holds, but also some real-life situations in which it may *not* hold.

Finally, it is also important to discuss about the relative effectiveness of the forces and processes variant of the system approach to energy analysis. The results of ANCOVA showed that the between-group differences (FV and PV) were not statistically significant. Taking into account that students at all educational levels experience many difficulties with the force concept (Aviani et al., 2015), as well as that the forces approach is characterized by a more complex terminology, before beginning of the intervention the process approach was expected to be more suitable for the upper-secondary school context. However, that both interventions proved to be equally effective is consistent with the teacher-experimentator's observations according to which students from both groups successfully processed the learning material and readily participated in classroom discussions. This could be explained by the fact that students from both groups were provided with carefully prepared scaffolds (e.g., visually represented strategy, worksheets with guiding questions etc.) which helped them to learn even such a complex topic as LCME (De Jong, 2006). In fact, all aspects of a complex idea should be represented systematically and in a coherent way that helps the students to develop robust and integrated conceptual understanding of energy needed to explain real-life phenomena (Bryce & MacMillan, 2009; Jin & Wei, 2014).

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Research Limitations

The main limitation of this research is that the research design did not include a conventional control group. Therefore, it is important to discuss some alternative explanations for the observed learning gains (Shadish et al., 2002, p.55). Maturation as an alternative explanation can be ruled out because of the relative short time span of intervention duration of 3 weeks. Similarly, history as an alternative explanation is highly improbable, because to our knowledge there were no concurrently occurring events that could have helped the students to learn more about LCME. Attrition is also a weak alternative explanation because only one respondent missed pre-test, and two missed post-test, so 3 student's responses in total were excluded from both, pre-test and post-test data. Finally, instrumentation cannot explain the learning gains neither because the same instrument has been used at pre-test and post-test. However, this exposure to the one and the same test before and after intervention could also represent a threat to internal validity on its own. In fact, it cannot be ruled out that repeated exposure to the same test could be partially responsible for the observed learning gain. However, there are solid arguments towards the fact that the testing threat to internal validity was not serious. Concretely, the students were not told that they would take the same test twice and they were told that the test wouldn't be graded. Furthermore, the teacher observed that the students successfully applied the introduced strategies in the mere classes, which speaks for the fact that the intervention effect was genuine.

One could also assert that the learning gain resulted only from the fact that student groups included in this study had conventional LCME teaching of very low quality. However, it could be shown that for a comparable group of students from another Canton Sarajevo gymnasium, as well as for a group of University Zagreb students, the test scores after taking conventional LCME teaching were also relatively low (Table 4).

Conclusions and Implications

Conventional teaching typically does not provide the upper-secondary students with explicit strategies that facilitate reasoning about LCME. As a result, students approach LCME problems by remembering superficially similar situations that were discussed in classes, and fail to transfer their knowledge to real-life problems.

From the results of this research, it can be concluded that only 3 hours of systems-based teaching about LCME may substantially improve upper-secondary school students' understanding about LCME. In other words, the system approach to energy analysis may work well not only in the university classes, but also in the context of upper-secondary school classes. To that end it is important to carefully introduce the systems concept and to discuss about system's evolution over time. Also, an explicit strategy for reasoning about LCME should be provided and applied to real-life situations through the use of the scaffolding-and-fading technique. Thereby, real-life situations may be created through hands-on demonstrations or observations of videos. Both can serve as an anchor for productive classroom discussions.

This research has important implications for the practice:

1. It synthesizes suggestions from earlier research into a unique system-based approach to energy analysis that may work well at the upper-secondary school context. Two variants of the approach are described in detail. These two variants may meet the needs of a whole variety of teachers and curricular contexts.
2. It provides an instrument for measuring understanding about LCME, which may be used for identifying students' difficulties with LCME, as well as for sparking interesting classroom discussions. The instrument is mostly composed of original test items.

Taking into account that effectiveness of teaching generally depends on the interaction of students and learning environment characteristics, it is necessary to conduct additional studies to explore how the two variants of the system approach to energy analysis work across a whole variety of student populations.

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Asila Halilović
(Corresponding author)
Master of Science in Physics Education, Physics Teacher, First Bosniak Gymnasium Sarajevo, Petrakijina 22, 71 000 Sarajevo, Bosnia and Herzegovina.
E-mail: asila.halilovic@bosnjackagim.edu.ba
ORCID: https://orcid.org/0000-0002-0872-2150

Vanes Mešić
PhD in Physics Education, Associate Professor in Physics Education, Faculty of Science at University of Sarajevo, Zmaja od Bosne 35, 71 000 Sarajevo, Bosnia and Herzegovina.
E-mail: vanes.mesic@gmail.com
ORCID: https://orcid.org/0000-0003-3337-3471

Elvedin Hasović
PhD in Physics, Associate Professor, Faculty of Science at University of Sarajevo, Zmaja od Bosne 35, 71 000 Sarajevo, Bosnia and Herzegovina.
E-mail: e.hasovic@pmf.unsa.ba

Andrej Vidak
PhD in Physics Education, Postdoctoral Research Assistant, Faculty of Chemical Engineering and Technology, University of Zagreb, Savska cesta 16, 1000 Zagreb, Croatia.
E-mail: avidak@fkit.hr
ORCID: https://orcid.org/0000-0002-3669-6762